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Is there a relationship between chronic low back pain and spinal sagittal balance? A prospective controlled study.

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ABSTRACT

Aims: Evaluation of whether there is a significant relationship between chronic low back pain and spinal sagittal alignment

Methods: This prospective, controlled study was conducted between April 2023 and September 2023, among patients aged 18-50, who complained of chronic low back pain and a healthy control (HC) group. In addition to the participant's demographic information, sagittal vertical axis (SVA), thoracic kyphosis (TK), and lumbar lordosis (LL) values on the lateral whole-spine radiograph and degenerations on the lumbar vertebra MRI were compared. Visual analogue scale (VAS) and ODI scores of the patients were also included in the statistical evaluation.

Results: A total of 64 participants (44 patients, 20 controls) were included in the study. There was no significant difference in age, gender, body mass index (BMI). SVA significantly increased in the patient group ($p<0.001$), but not LL and TK. In a linear discriminant analysis (LDA), SVA discriminates 100% of the two groups. No significant correlation was observed between VAS and ODI scores and the patients' age, gender, BMI, and spinal parameters.

Conclusion: SVA is a crucial parameter of spinal balance, and as shown in this study, deviations from normal SVA appear to be a significant contributor to low back pain. We recommend an easy-to-implement and cost-effective method for assessing SVA in evaluating and treating patients with chronic low back pain.

Keywords: Low back pain, lumbar lordosis, oswestry disability index, spinal sagittal balance, sagittal vertical axis, thoracic kyphosis

INTRODUCTION

Low back pain (LBP) is one of the most common reasons for seeking medical treatment.[1] While 95% of patients experience relief from their pain within the first three months,[2] LBP is a leading symptom that accounts for workday losses and disability.[3,4] The most common etiologies of LBP include myofascial pain, facet-mediated pain, discogenic pain, spinal stenosis, trauma, and neoplasms. However, only 10-20% of patients can be diagnosed with a precise pathoanatomical condition, and most cases are non-specific.[5] These etiologies vary from patient to patient, and management of LBP also varies; not every patient responds the same to similar treatment.[6] Despite the various guidelines for managing LBP, some patients' pain does not entirely subside, or even if there is relief, the complaints may recur after a while. This situation has prompted further studies in the field of low back pain.

In recent years, numerous studies have explored the biomechanics of the spine, uncovering that spinal curves collectively maintain a state of equilibrium. Normal sagittal spinal alignment plays a critical role in maintaining an upright posture while minimizing muscle energy expenditure. Disruption of this alignment increases the load on the muscles, leading to muscle fatigue and is believed to be a contributing factor in the development of chronic pain.

The fact that we do not fully understand the etiology of chronic low back pain, which significantly impacts people's functionality, emphasizes the need for further research in this field. When there is pain in the lower back, it is possible to focus solely on the lumbar region and forget the fact that the entire spine functions as a whole. The patient's pathology can be overlooked in this process. We believe that if the connection between lower back pain and spinal sagittal balance is clearly understood,

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the concept of nonspecific lower back pain will largely disappear. With this understanding, we can offer patients diagnoses and treatment options to correct spinal sagittal balance. Many studies have compared radiological data, but the number of publications evaluating the patient's pain and disability simultaneously is low. According to this objective, in this study, we aimed to assess whether a significant relationship exists between sagittal spinal alignment parameters in patients with chronic low back pain and age, sex, body mass index (BMI), the severity of their pain, functionality, and lumbar MRI findings.

METHODS

This prospective, controlled study was conducted between May 2023 and September 2023 in the Department of Neurosurgery at University of Health Sciences, Van Training and Research Hospital. This study was performed after approval by the Ethics Committee of University of Health Sciences Van Training and Research Hospital (Date: 26.04.2023, Decision No: 2023/09-03). All subjects signed detailed informed consent before their inclusion in the study. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Specific selection criteria were applied to minimize study bias and ensure consistent results. Male and female patients aged from 18 to 50 who had experienced LBP for more than three months (chronic LBP) were included. The following exclusion criteria were applied: (1) Patients with a history of spinal surgery; (2) chronic diseases that may affect spinal alignment like rheumatoid arthritis or ankylosing spondylitis; (3) complaints of leg pain (4) history of lower extremity pathologies like osteoarthritis (5) findings such as disc protrusion or extrusion, spondylolisthesis, spinal stenosis, congenital defect, tumor, infection, fracture or any finding that need for surgical intervention in radiological imaging. We also excluded patients who had been receiving painkillers or spasmolytic agents at the time of application to the hospital, which may affect the reliability of the study. Additionally, we also included normal subjects free from LBP and leg pain for the healthy control (HC) group.

The collected data for each subject included age, sex, height, weight, and BMI. For the patient's group, the duration of LBP was recorded. Pain intensity was assessed using the visual analogue scale (VAS), which ranged from 0 to 10 points (0 point=no pain, 10 points= worst pain possible). To evaluate patients' disability, we utilized the oswestry disability index (ODI), a self-administered questionnaire[10,11] on a scale ranging from 0 to 100%. The obtained scores were associated with varying degrees of disability, ranging from minimal to bedbound.

All subjects underwent non-contrast lumbar vertebrae magnetic resonance imaging (MRI) and lateral long cassette radiographs of the entire spine. Lateral radiography was performed with subjects standing in their most relaxed position, shoulders flexed, and forearm extended. All radiographs were taken using the same technique, the same radiography device, with a constant distance between the subject and the radiographic source. On the lateral radiographs, the following measurements were performed: distance between C7 plumb line and the posterior superior corner of the sacrum endplate -Sagittal vertical axis (SVA), Cobb's angle between superior endplate of T4 and inferior endplate of T12- thoracic kyphosis (TK), Cobb's angle between superior endplate of L1 and superior endplate of S1- lumbar lordosis (LL)[12] (Figure 1). In the case of SVA, values are considered positive when the plumb line is located anteriorly, whereas they are considered negative when the plumb line is positioned posteriorly. These measurements were independently performed by two neurosurgeons, and the average values were recorded.

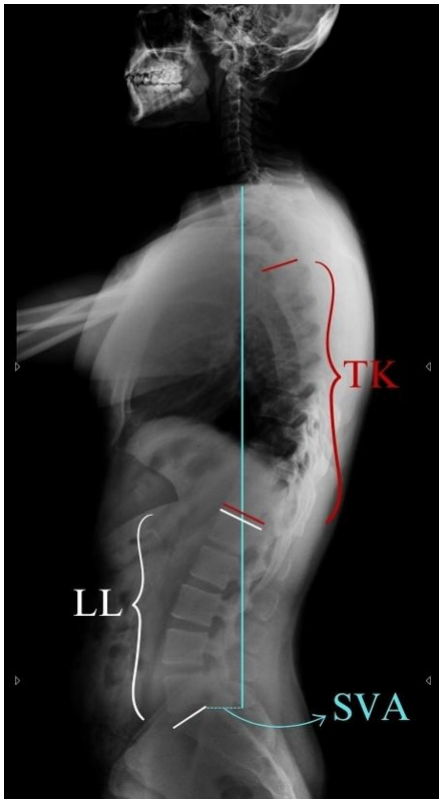

Figure 1. The figure shows how SVA, TK and LL measurements are made.
Note: TK: Thoracic kyphosis, LL: Lumbar lordosis, SVA: Sagittal vertical axis

Lumbar vertebra MRIs, which include T1 and T2 weighted sagittal images and T2 weighted axial images, were interpreted similarly by two neurosurgeons. Lumbar disc degenerations were evaluated using the

Priffman degeneration grading scale.[13] For patients with more than one level of degeneration on lumbar MRI, the number of degenerated levels was noted, and the Priffman degeneration grade (PDG) of the most degenerated level was used.

Statistical analysis was conducted using IBM Statistical Package for Social Sciences (SPSS) version 20.0 (IBM, NY, USA). Following each variable's assessment for normality of data distribution, skewness, kurtosis, and histogram plots were examined. Continuous variables were presented as mean and standard deviation (SD), while categorical variables were expressed as percentages or frequencies. Parametric tests, including two-tailed Student's t-tests and partial correlations, were employed for variables with a normal distribution. The chi-square test was used to compare categorical variables. For SVA, TK, and LL (dependent variables), an analysis of covariance (ANCOVA) was performed, with diagnostic groups as a fixed factor and age, BMI, and PDG as covariates. Linear discriminant analysis (LDA) was employed to assess the angles' ability to discriminate among groups, with standardized canonical discriminant function coefficients used to determine the variables contributing to a more accurate classification of the two groups. Significance was set at $p \leq 0.025$ for Bonferroni-corrected ANCOVA to reduce type I errors and $p \leq 0.05$ for other comparisons, with all tests being two-tailed. Effect sizes were measured using Cohen's d, partial Eta-squared, and Pearson's r.

RESULTS

A total of 80 participants were initially invited to participate in the study; however, 11 of them were subsequently excluded based on the exclusion criteria. Four participants were excluded due to extruded lumbar disc herniation observed on lumbar MRI scans, one participant's lateral whole spine radiogram did not meet the scanning criteria, eight participants had chronic diseases, and three were taking spasmolytic medication during the examination. This study enrolled 44 patients and 20 HCs for the final analysis. In the patient group, there were 15 males (34%) and 29 females (66%), while the HC group consisted of nine males (45%) and 11 females (55%). No significant differences were observed in gender, age, body weight, and BMI between the two groups. The mean VAS score was 6.41±SD, and the mean ODI was 41.05%±SD. The median number (IQR) of degenerated levels was 1 (0-1) for both groups, and the median PDG for the most degenerated level was 2 (0-3) for both groups. There were no significant differences in these parameters. Demographic and clinical data are summarized in Table 1.

We found significant differences between the groups using two-tailed t-tests with SVA, but not with TK and LL. Figure 2 shows these analyses. Specifically, SVA values were significantly higher in patients with LBP compared to HCs ($p<0.001$, Cohen's $d=1.03$). Furthermore, after adjusting for age, BMI, and PDG, ANCOVA analysis confirmed that SVA remained significantly higher in patients with LBP ($F=10.125$, $p=0.002$, $\eta p^2=0.15$). In contrast, no significant differences were observed in TK and LL. Additionally, SVA was significantly higher among female patients ($p=0.036$). Table 2 presents the Bonferroni-corrected results among the groups.

Table 1. Demographic and clinical characteristics of the participants

Characteristics	Patient with low back pain (n=44)	Controls (n=20)	P-value
Age (years)	30.86±8.4	33.95±7.77	0.186
Gender (female)	29 (66%)	11 (55%)	0.403
Body Weight (kg)	69.64±13.21	68.5±11.25	0.74
BMI (kg/m²)	25.32±4.99	24.78±3.54	0.666
Duration of the pain [months, median (IQR)] *	12 (4-24)		
VAS score	6.41±1.9 (Min: 2, Max: 10)		
ODI (%)	41.05±12.9 (Min: 14, Max: 78)		
PDG*, **	2 (0-3)	2 (0-3)	0.604
Number of degenerated level on lumbar MRI *	1 (0-1)	1(0-1)	0.695
SVA (mm)	-32.11±34.45 (-102 to 55)	0.62±29.09 (-62 to 90)	<0.001
TK (°)	36.58±8.48 (Min: 17, Max: 51)	39.63±10.3 (Min: 22, Max: 56.8)	0.218
LL (°)	57.93±12.04 (Min: 35.4, Max: 88.1)	56.12±11.83 (Min: 38.7, Max: 75.7)	0.578

Note: Plus–minus values are given as mean ± standard deviation, non-normally distributed data were given as median (interquartile). BMI: Body mass index, TK: Thoracic kyphosis, LL: Lumbar lordosis, Min: Minimum, Max: Maximum, ODI: Oswestry Disability Index, PDG: Priffman degeneration grade, SVA: Sagittal vertical axis, VAS: Visual analogue score, *: Median values, ** Priffman degeneration grade of the most degenerated level

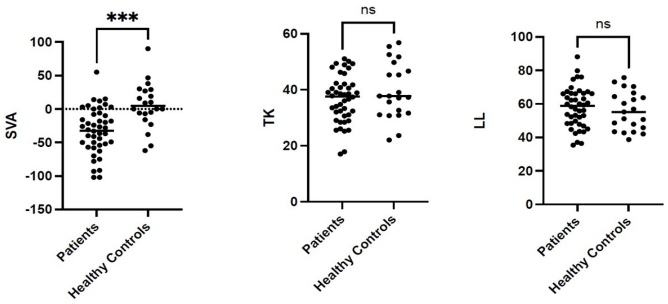

Figure 2. Figure shows results in two groups.
Note: *** p<0.001, TK: Thoracic kyphosis, LL: Lumbar lordosis, ns: non-significant, SVA: Sagittal vertical axis.

Table 2. Bonferroni-corrected ANCOVA results of parameters

	Patients (n=44)	HC (n=20)			
Parameters	**Estimated marginal means ± standard error[a]**		**F**	**p**	**ηp^2**
SVA (mm)	-31.072±5.05	-1.65±7.59	10.13	**0.002[b]**	0.15
TK (°)	36.804±1.31	39.142±1.97	0.949	0.334	0.02
LL (°)	58.076±1.796	55.792±2.7	0.483	0.49	0.008

Note:
[a] adjusted for age, body mass index and Priffman degeneration grade of the most degenerated level
b Significantly different: p≤0.025
TK: Thoracic kyphosis, LL: Lumbar lordosis, SVA: Sagittal vertical axis.

TK values and the number of degenerated levels had weak and very weak correlations between age, respectively (r=0.329 p=0.031, r=0.352 p=0.020). After controlling for age and BMI, we conducted partial correlations between SVA, TK, and LL and clinical variables. Table 3 presents the partial correlation matrix. We found a significant relationship between SVA and LL (r=-0.501, p<0.001). TK scores were associated with LL scores (r=0.377, p=0.015) but not with SVA (p=0.71). VAS scores significantly correlated with the ODI scores (r=0,521, p<0.001). However, SVA, TK, and LL did not correlate significantly with the VAS and ODI scores (all p>0.05). Furthermore, there were no significant relationships between SVA and the duration of pain symptoms or body weight of the patients, even after controlling for age and BMI (all p>0.05).

Table 3. Correlation analysis results (r-values) after controlling for age and BMI

Variables	SVA	TK	LL
Duration of pain	0.072	0.023	-0.048
Body Weight	0.222	-0.042	0.062
VAS	-0.205	-0.135	0.108
ODI	-0.037	-0.131	0.019
PDG on MRI	-0.054	0.033	-0.023
Number of Degenerated Level on MRI	-0.09	-0.008	0.099
SVA	-	-0.60	**-0.501****
TK	-0.60	-	**0.377***

Note: *<0.05, **<0.001. TK: Thoracic kyphosis, LL: Lumbar lordosis, ODI: Oswestry Disability Index, PDG: Priffman degeneration grade, SVA: Sagittal vertical axis, VAS: Visual analogue score.

As a final step, a linear discriminant analysis was employed to assess the discriminative ability of the SVA between patients with LBP and HCs. The overall model yielded statistical significance, with Wilk's λ at 0.82, $\chi 2$=12.21, p<0.001, and explained 100% of the variance in predicting the difference between the two groups (patients vs. HCs). The overall effect size of the model, as indicated by the canonical correlation value, was 0.42.

DISCUSSION

The "Cone of Economy" theory, as described by Dubousset[9], has shed light on our understanding of spinal balance. The axial skeleton aligns itself within a compact cone shape, minimizing muscle activity and serving as the key to energy conservation. When spinal balance is disrupted, this cone, whose base is on the cranial side, grows and results in increased energy expenditure required for maintaining an upright posture. This, in turn, triggers muscle fatigue and initiates the pain process. While several authors have explored spinal alignment concerning low back pain[14-21], the precise connection between sagittal alignment and low back pain remains incompletely understood. Many of these studies have overlooked evaluating patients' pain and disability. In this study, we assessed spinal alignment and considered both the pain and disability of the patients, seeking to identify any statistically significant differences.

While women showed higher VAS and ODI scores, as well as a longer symptom duration, we did not observe any statistically significant differences between patients and healthy controls (HCs) regarding age, gender, BMI, symptom duration, VAS and ODI scores, PDG, and the number of degenerate levels.

In the general population, no established norm for sagittal balance exists.[22] Therefore, we conducted this study with a HC group. The main difference between patients and HCs was observed in terms of SVA. The mean SVA for patients was -32.11, while for HCs, it was 0.62. SVA exhibited a statistically significant posterior shift relative to the S1 endplate in patients. Even after excluding age, sex, BMI, and PDG as confounding factors, SVA remained significantly higher in the patient group. Several publications have previously identified a relationship between SVA and low back pain[14,16,20,21], and our study contributes to the existing literature by further supporting these findings. Also, with linear discriminant analysis, we saw that SVA discriminates between the two groups powerfully (explaining 100% of the variance). This strongly indicates that SVA may be essential for evaluating patients with chronic low back pain.

While TK was slightly lower and LL was slightly higher in patients, we did not observe any significant differences between the two groups. Following partial correlation analysis, we identified a moderate correlation between LL and SVA and a weak correlation between TK and LL in patients. We thought an increase in LL results in a significant posterior displacement of SVA and a decrease in TK. Similar to present study, some prior studies[17,23]

did not find a significant difference in LL between patient and control groups. However, in studies where disc herniation and degeneration played a prominent role[18,19,24], a significant decrease in LL was observed; this decrease in LL leads to an anterior shift of SVA.[14,20] These structural changes are primarily attributed to the loss of intervertebral disc height, the reduction of lordosis, and the compensatory anterior displacement of the C7 plumb line. In our study, since most patients had standard lumbar disc heights (only three patients had grade four PDG, while the rest had grade three or lower PDG), we postulated that patients tend to perform lumbar extension to alleviate lumbar muscle tension, increasing lumbar lordosis. This increase in lumbar lordosis manifests as a posterior shift in SVA and leads to decrease in TK. Following the 'cone of economy' theory, expanding the cone due to increased SVA places a more significant workload on the lower back muscles, leading to muscle fatigue and chronic pain.

Hira et al.[21] and Sardar et al.[24] demonstrated a correlation between TK and age. Consistent with these findings, our present study revealed that TK increases with age. Myatani et al.[25] also identified a significant loss in truncal muscle volume with age, which may explain the observed increase in TK with age.

In this prospective study, our focus was on patients with chronic low back pain who did not have radicular pain. To enhance data reliability, we established a control group. In contrast to many studies in the literature, we assessed not only the radiological images of the patients but also their subjective assessments, including VAS and ODI scores.

Limitations

We are aware that this study has some strengths as well as some weaknesses (1) a cross-sectional assessment, (2) a relatively small number of subjects. We know that a multicenter study with a more prominent participant must provide more comprehensive results.

CONCLUSION

SVA is a critical parameter for assessing spinal balance, and as demonstrated in the present study, deviations from the normal SVA appear to play a significant role in the development of low back pain. We acknowledge the importance of further research into the factors influencing SVA. Therefore, we recommend an easy-to-implement and cost-effective method to assess SVA in evaluating and treating patients experiencing chronic low back pain.

Abbreviations

BMI: Body mass index

HC: Healthy control

LBP: Low back pain

LDA: Linear discriminant analysis

LL: Lumbar lordosis

MRI: Magnetic resonance imaging

ODI: Oswestry disability index

PDG: Priffman degeneration grade

SVA: Sagittal vertical axis

ETHICAL DECLARATIONS

Ethics Committee Approval: This study was performed after approval by the Ethics Committee of University of Health Sciences Van Training and Research Hospital (Date: 26/04/2023, Decision No: 2023/09-03).

Informed consent: All subjects signed detailed informed consent before their inclusion in the study.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

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